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REVIEW OF TRACE V5.0

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SUMMARY

This document reports about the review of the TRACE V5.0 code based on the documentation including the Theory Manual, the Assessment Manual, and to a less extent the Users Guide. It focussed mainly on field equations and closure models, on a few flow process models, and on their assessment. This evaluation considered assessment against Separate Effect Tests and only the Integral Effect devoted to PWR LBLOCAs.

The importance with regard to safety of each closure model or flow process model is underlined by estimating his sensitivity in accidental transients. One must mention here that the culture of the author of this review is more extended in accidental transients of PWRs than of BWRs. The correctness and adequacy of the each model or submodel is evaluated with regard to the up to date knowledge on the corresponding flow process, considering also the consistency with the intrinsic limitations of the two-fluid model. The degree of empiricism of the selected model is also evaluated with regard to the physical understanding of the corresponding flow process. Then the validation of each model or submodel in a Separate Effect approach is evaluated based on the Assessment Manual. The adequacy of the Theory Manual is also evaluated. At last, for some closure model or flow process model, recommendations are given either for improving the documentation in the respective subsection of the Theory manual, or for proposing additional R&D work in view of improving the model, or even for proposing additional validation.

The main results of this review are:

TRACE V5.0 appears to be a good system code with extended capabilities for simulations of LOCAS of PWRs and BWRs. An impressive work has been done to revisit all closure models, considering recent published work to improve some old correlations of the previous generation of codes (RELAP and TRAC), implementing many improvements, and finally providing a coherent and rather simple set of models. Most closure models and flow process models which were evaluated seem to be adequate and to reflect the present state of the art. The degree of empiricism of most closure model is consistent with the available physical understanding of the basic flow processes. Mechanistic models were selected or developed when it was possible, some tuning on experimental data was added when necessary, and pure empirical models were selected when no other approach could do a better job.

However a few models which are not validated in conditions representative of the reactor application may have an unnecessary degree of sophistication which cannot demonstrate any improved predictive capabilities. A few models may require further analysis and further improvements, such as the Direct Contact Condensation, the top-down reflooding, interfacial transfers in presence of noncondensable gases, the stratification criterion.

Although this evaluation did not address the numerical scheme, it is observed in calculations of the oscillating manometer and of the expulsion of steam by subcooled water that the Level Tracking Method of TRACE V5.0 performs remarkably well.

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The available assessment against SETs and IETs validates many models and covers many physical situations encountered in accidental transients. However some validation calculations are not sufficiently analysed and additional assessment is still required for a more exhaustive coverage of each model and of all important phenomena encountered in reactor transients.

No big flaw was identified in the modelling which might lead to wrong predictions and to erroneous conclusions on safety issues. However some checks on some models and some additional assessment are necessary to finally demonstrate that there is no flaw and a few model improvements are recommended that might improve the accuracy of predictions.

The documentation of the physical modelling in the Theory manual gives not only the selected equations and closure models but also some justification of the choices, which is useful and appreciated by users. Some recommendations are given to improve the documentation in particular for the 3D pressure vessel.

The documentation of the Validation and Verification in the Assessment Manual presents the general assessment methodology based on PIRT tables and the results of each SET or IET simulation. Recommendations are given to improve the analysis of some calculations, to relate each assessment work with the PIRT table, to include some recommendations to users based on assessment work (e.g. recommendations on mesh size and time step), to add a cross reference matrix with all models against the SET matrix, and to give the range of parameters in which each closure law is validated in a separate effect way.

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1 INTRODUCTION

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A section of this report is devoted to the assessment. The general assessment matrix and methodology are evaluated and each Separate Effect test and Integral Effect Test calculation devoted to PWR LBLOCAs is evaluated in separate subsections. Recommendations are given for additional analysis of the assessment calculations and for extending the assessment program.

At the end of this report one gives first some general conclusions about the correctness of the models, adequacy of the assessment and the content of the documentation. Then one summarizes all recommendations, ranked by the relative importance and classified in recommendations for improving the models, improving the assessment and improving the documentation.

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10 REFERENCES

[1] P. Bazin, G. Geffraye, G. Serre, Physical laws of CATHARE Revision 6.1 pipe module, DTP/SMTH/LMDS/EM/2002-096

[2] D. Bestion, L. Gros d'Aillon, *Condensation tests and interpretation - the Cathare condensation model,* 4th Int. Topical Meeting on Nuclear Reactor Thermalhydraulics, NURETH 4, Karlsruhe 1989

[3] A. Janicot, D. Bestion, *Condensation modelling for ECC injection*, Nuclear Engineering & Design, 145 (1993) 37-45

[4] D. Bestion, *The physical closure laws in the Cathare code*, Nuclear. Engineering & Design, 124 (1990) 229-245

[5] D. Bestion, J.C. Micaelli, *A two-fluid stratified model suitable for a PWR safety code*, 4th Miami Int. Symposium on Multiphase Transport & Particulate Phenomena, 1986

[6] P. Coste , D. Bestion, *A simple modelling of mass diffusion effects on condensation with noncondensable gases for the Cathare code*, 7th Int. Topical Meeting on Nuclear Reactor Thermalhydraulics NURETH 7, Saratoga Springs, Sept 10-15, 1995

[7] R. Freitas , D. Bestion, *On the prediction of the flooding phenomenon with the Cathare code*, 6th Int. Topical Meeting on Nuclear Reactor Thermalhydraulics, NURETH 6, Grenoble, Oct.5-8, 1993